# Escalares inertes como candidatos a materia oscura en un modelo con simetría de norma local

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# Materia Oscura

Candidatos a Materia Oscura → Axions, gravitinos, neutralinos, majorons, WIMP, etc…

WIMP → Scalars

- Neutral
- Cold
- Stable
- BBN

Abundancia (Relic density Ω)

$$\frac{dn_\chi}{dt} + 3Hn_\chi = -\langle \sigma_{\chi\bar{\chi}}|v| \rangle \left(n_\chi^2 - n_{\chi,\mathrm{eq}}^2\right)$$

Ecuación de Boltzmann

$$\Omega h^2_{CDM} = 0.1199 \pm 0.0027.$$

P. A. R. Ade *et al.* [Planck Collaboration], *Astron. Astrophys.* (2014), astro-ph.CO/1303.5076.

# Inert Doublet Model

Bajo una simetría discreta $Z_2$ $\begin{cases} \Phi_1 \to \Phi_1 \\ \Phi_2 \to -\Phi_2 \end{cases}$

$$\Phi_1 = \begin{pmatrix} \phi^{\pm} \\ \phi_0 \end{pmatrix} \qquad \Phi_2 = \begin{pmatrix} H^{\pm} \\ (S + iA)/\sqrt{2} \end{pmatrix}$$

$$V = \mu_1^2|\Phi_1|^2 + \mu_2^2|\Phi_2|^2 + \lambda_1|\Phi_1|^4 + \lambda_2|\Phi_2|^4 + \lambda_3|\Phi_1|^2|\Phi_2|^2 + \lambda_4|\Phi_1^\dagger\Phi_2|^2 + \lambda_5(\Phi_1^\dagger\Phi_2 + h.c.)$$

$$M_h^2 = 2\lambda_1 v^2$$

$$M_{H^\pm}^2 = \mu_2^2 + \frac{1}{2}\lambda_3 v^2$$

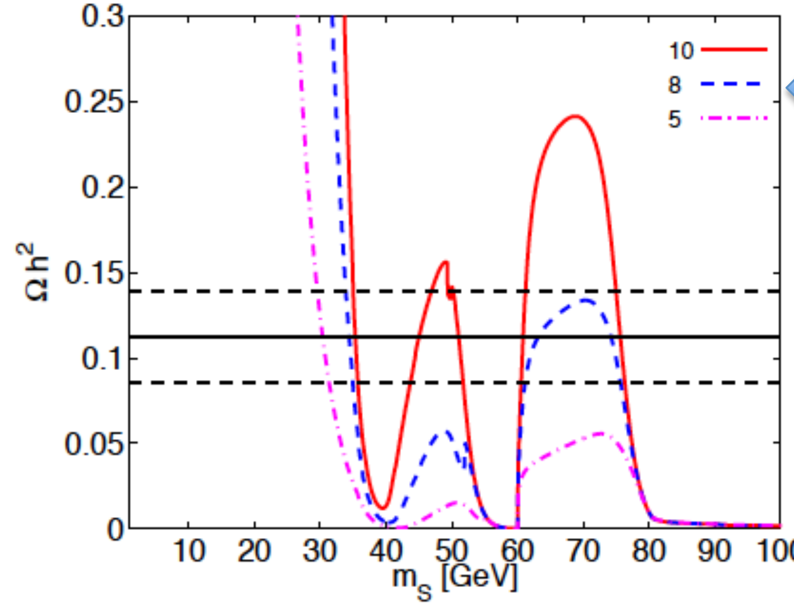
$$M_{S,A}^2 = \mu^2 + \frac{1}{2}(\lambda_3 + \lambda_4 \pm \lambda_5)v^2$$

The Inert Dark Matter

Ethan M. Dolle*, Shufang Su†

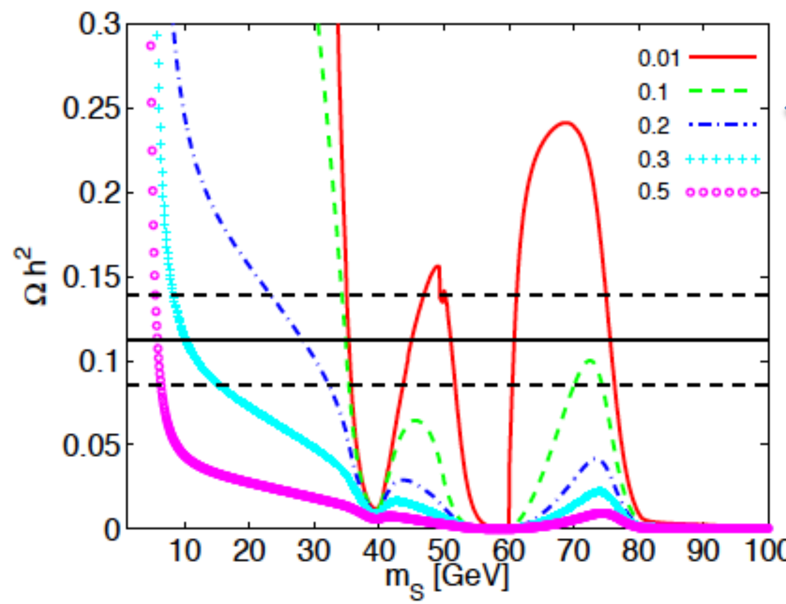
Phys. Rev. D80, 055012 (2009)

$$\delta_1 = M_{H^\pm}^2 - M_S^2$$
$$\delta_2 = M_A^2 - M_S^2$$
$$\lambda_L = \lambda_3 + \lambda_4 + \lambda_5$$




$\delta_2$

$$\delta_1 = 50GeV,\ \lambda_L = 0.01$$




$\lambda_L$

$$\delta_1 = 50GeV,\ \delta_2 = 10GeV$$

# Inert Doublet Model with extra gauge symmetry $U(1)'$

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The scalar fields are denoted as $\Phi_1$, $\Phi_2$ for doublets and $\Phi_X$ for singlet

$$\begin{aligned}
\Phi_1 &\sim (1,2,1/2,x_1),\\
\Phi_2 &\sim (1,2,1/2,x_2),\\
\Phi_X &\sim (1,1,0,x),
\end{aligned}$$

For these scalar fields the most general

$$\begin{aligned}
V \;=\;& \mu_1^2\Phi_1^\dagger\Phi_1 + \mu_2^2\Phi_2^\dagger\Phi_2 + \mu_x^2\Phi_x^*\Phi_x + \left[\mu_{12}^2\Phi_1^\dagger\Phi_2 + h.c.\right]\\
&+\lambda_1\left(\Phi_1^\dagger\Phi_1\right)^2 + \lambda_2\left(\Phi_2^\dagger\Phi_2\right)^2 + \lambda_3\left(\Phi_1^\dagger\Phi_1\right)\left(\Phi_2^\dagger\Phi_2\right)\\
&+\lambda_4\left|\Phi_1^\dagger\Phi_2\right|^2 + \left[\lambda_5\left(\Phi_1^\dagger\Phi_2\right)^2 + \lambda_6\left(\Phi_1^\dagger\Phi_1\right)\left(\Phi_1^\dagger\Phi_2\right)\right.\\
&\left.+\lambda_7\left(\Phi_2^\dagger\Phi_2\right)\left(\Phi_1^\dagger\Phi_2\right) + h.c.\right] + \lambda_x\left(\Phi_x^*\Phi_x\right)^2\\
&+\left(\Phi_x^*\Phi_x\right)\left[\lambda_{1x}\left(\Phi_1^\dagger\Phi_1\right) + \lambda_{2x}\left(\Phi_2^\dagger\Phi_2\right)\right]\\
&+\left[\lambda_{12x}\left(\Phi_1^\dagger\Phi_2\right)\left(\Phi_x^*\Phi_x\right) + h.c.\right] + \left[\lambda'_{1x}\left(\Phi_1^\dagger\Phi_1\right)\Phi_x\right.\\
&\left.+\lambda'_{2x}\left(\Phi_2^\dagger\Phi_2\right)\Phi_x + \lambda'_x\left(\Phi_1^\dagger\Phi_2\right)\Phi_x + h.c.\right]
\end{aligned}$$

The term $\left(\Phi_1^\dagger \Phi_2\right)\Phi_x$, which induces decay of the DM candidate,

$$x_2 - x_1 \neq x. \quad \Rightarrow \quad (\, x_1,\ x_2,\ x_3\,) = (\, 0,\ -x,\ x\,) \text{ with } x \neq 0.$$

$$\begin{aligned} V \ = \ & \mu_1^2 \Phi_1^\dagger \Phi_1 + \mu_2^2 \Phi_2^\dagger \Phi_2 + \mu_x^2 \Phi_x^* \Phi_x + \lambda_1 \left(\Phi_1^\dagger \Phi_1\right)^2 \\ & + \lambda_2 \left(\Phi_2^\dagger \Phi_2\right)^2 + \lambda_3 \left(\Phi_1^\dagger \Phi_1\right)\left(\Phi_2^\dagger \Phi_2\right) + \lambda_4 \left|\Phi_1^\dagger \Phi_2\right|^2 \\ & + \lambda_x \left(\Phi_x^* \Phi_x\right)^2 + \left(\Phi_x^* \Phi_x\right)\left[\lambda_{1x}\left(\Phi_1^\dagger \Phi_1\right) + \lambda_{2x}\left(\Phi_2^\dagger \Phi_2\right)\right] \end{aligned}$$

After spontaneous symmetry breaking

$$\langle \Phi_1 \rangle = \begin{pmatrix} 0 \\ \frac{v}{\sqrt{2}} \end{pmatrix}, \qquad \langle \Phi_2 \rangle = \begin{pmatrix} 0 \\ 0 \end{pmatrix} \qquad \langle \Phi_x \rangle = \frac{v_x}{\sqrt{2}}.$$

The masses of the physical scalar are

$$\begin{aligned} M_{h1}^2 &= 2\lambda_1 v^2, \\ M_{h2,h3}^2 &= \mu_2 + \frac{1}{2} v^2 \left(\lambda_3 + \lambda_4\right) + \frac{1}{2} v_S^2 \lambda_S, \\ M_{H\pm}^2 &= \mu_2 + \frac{1}{2} v^2 \lambda_3 + \frac{1}{2} v_S^2 \lambda_S, \\ M_S^2 &= 2\lambda_6 v_S^2, \end{aligned}$$

The interactions between the scalar and gauge bosons are given by

$$\mathcal{L}_{\text{scalar}} = |D_\mu \Phi_1|^2 + |D_\mu \Phi_2|^2 + |D_\mu \Phi_x|^2,$$

where the covariant derivative $D_\mu$ is defined as

$$D_\mu = \left(\partial_\mu + ig'Y\hat{B}_\mu + igT_3\hat{W}_{3\mu} + ig_{Z'}Q'\hat{Z}'_{0\mu}\right)$$

$$\begin{pmatrix} Z'_{0\mu} \\ B_\mu \end{pmatrix} = \begin{pmatrix} \sqrt{1-\varepsilon^2/\cos^2\theta_W} & 0 \\ -\varepsilon/\cos^2\theta_W & 1 \end{pmatrix} \begin{pmatrix} \hat{Z}'_{0\mu} \\ \hat{B}_\mu \end{pmatrix}$$

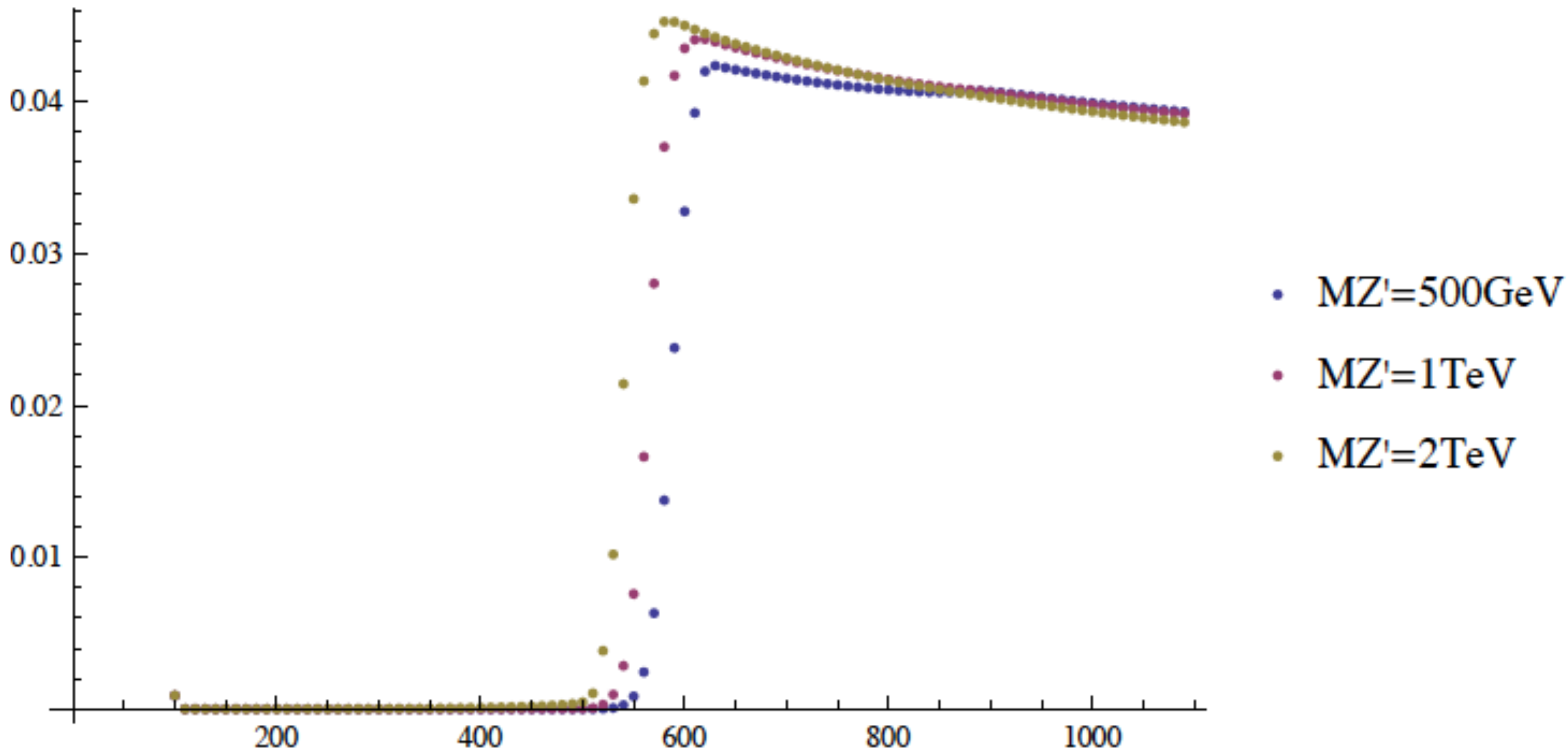
$$\mathcal{L} = \mathcal{L}_{gauge-masses} + \mathcal{L}_{gauge-scalar},$$

$$\mathcal{L}_{gauge-masses} = \frac{1}{2}m^2_{Z^0}Z^0Z^0 + \frac{1}{2}m^2_{Z'^0}Z'^0Z'^0 - \Delta^2 Z'^0Z^0 + \ldots$$

$$m^2_{Z^0} = \frac{1}{4}g_Z^2 v^2,$$

$$m^2_{Z'^0} = g^2_{Z'}(v^2 + v_S^2) + \frac{\varepsilon}{\cos\theta_W}g_{Z'}g'^2 + \frac{1}{4}\left(\frac{\varepsilon}{\cos\theta_W}\right)^2 g'^2 v^2,$$

$\Omega^2$ $\qquad$ $M_{singlet} = 500GeV$




$M_{DM}\ [GeV]$

$M_h = 126GeV$
$M_{H^\pm} = 600GeV$
$\lambda_3 = 0.1$

- LanHep 3.9 XXX,
- Micromegas 2.XXX

# Comentarios Finales

- Necesario incluir la información de las restricciones que impone los límites experimentales actuales.

- Estudiar el resto de las observables de materia oscura.

- Analizar el espacio de parametros y interpretar resultados .

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